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# Two-dimensional structure of nitrogen molecular bands radiation of microdischarges in DBD in $N_2$-$O_2$ mixtures: Numerical model

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*Two-dimensional structure of the microdischarge channel radiation in the second positive (0,0) molecular band of nitrogen in dielectric barrier discharge in nitrogen-oxygen mixtures between parallel plane electrodes is investigated by means of numerical modelling. The numerical results are applied for the explanation of experimental results.*

## 1. Introduction

Recent years highly spatio-temporally resolved experimental investigations using cross-correlation spectroscopy technique [1] were performed for the spectroscopic diagnostics of microdischarge local parameters in dielectric barrier discharges (DBD) in air. Usually the radial structure of the discharge channel was not taken into account however simulations [2] showed non-uniform radial profiles of streamer channel radiation. In recent investigation [3] the two-dimensional (both radial and axial) structure of microdischarge channel radiation was obtained experimentally. To explain the experimental results [1,3] numerical modelling of the single microdischarge evolution at the initial stage is made.

## 2. Mathematical model of DBD dynamics and radiation

Dielectric barrier discharge in a parallel-plane geometry with discharge gap d as shown in fig. 1 is considered. Atmospheric pressure gas in the gap consists of (100-p)% $N_2$ and p% $O_2$. The constant applied anode voltage $U_0$ and the cylindrical symmetry of the microdischarge channel are supposed. Dielectric permittivity of glass is $\varepsilon = 5$.

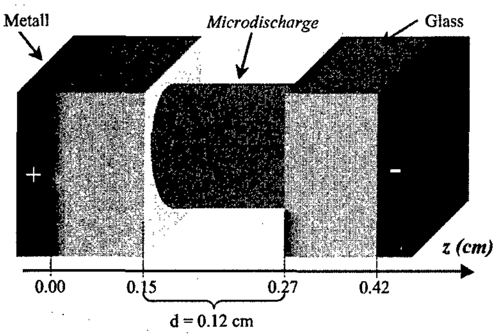


Figure 1: Geometry of DBD discharge.

Microdischarge plasma dynamics is described by the set of continuity equations for charged and excited species densities and Poisson equation for electrical potential [4]. Sources of particles by plasma kinetics both photoionization are taken into account. All the reactions rates are supposed to be dependent on the local reduced electric field strength.

The only two secondary processes: ion emission from the near-cathode dielectric surface (emission coefficient $\gamma_i$=0.01) and photoionization of a gas are included.

No charged or excited particles inside the gap at the initial state any are assumed. Single filament in DBD is initiated by single electron going directly from the near-cathode dielectric surface.

In the most previous simulations "single initial electron" was substituted by many (100-1000 and more) electrons and initial electric field was high enough following avalanche-to-streamer transition. This seems to be non-realistic for short gaps and can lead to incorrect conclusions as to DBD development stages.

Spontaneous radiation intensity for the (0-0) transition of the second positive system ($\lambda = 337.1$ nm) is calculated analogously to [5].

In the simulations of the experimentally measured quantities ideal spatial resolution is supposed. As the local radiation intensity the number of photons directed from the line crossing the point with coordinate ($r$,$z$) per surface area unit per time (photons/cm$^2$/s) is used.

## 3. Results of the numerical simulation and discussion

1) $p$=20 (artificial air), d = 0.12 cm (conditions [1]).

For $U_0$ = 9.18 kV the two-dimensional distribution for 337.1 nm is presented for $t$ =54.5 ns (filament arrival time at the cathode) in fig. 2, the axial dependence of discharge parameters is shown in fig. 3 and spatio-temporal radiation distribution is presented in fig. 4.

By the modelling results (fig. 3) after avalanche stage the relatively long time Townsend phase (till t=50 ns) characterized by charged particles accumulation takes place. Then it transforms to cathode-directed ionizing wave usually observed as filament.

As it is seen (fig. 2), initial decreasing of the radiation radius along the gap takes place, analogously to the corresponding experimental pictures in [3]. This is not characteristic for the streamer discharge radiation [5].

Under the term "streamer" let us denote a self-consistent ionization wave which: 1) has sufficiently high own electric field strength for propagation, 2) produces enough electrons before the tip (by photoionization) so

its movement is independent of possible electrons background. So we can distinguish between ionization waves controlled by preliminary background and "self-consistent" streamers. From the results [3] one can conclude that along almost all the gap the filament is not a real streamer and its dynamics is controlled by electrons background formed at the Townsend phase.
It can be seen in fig. 3, the ionization wave (from 50 ns, radius is decreasing, fig. 2) is following by real streamer (from 54 ns, radius is increasing), possessing almost constant concentration at the tip.
The simulated relatively long time near-anode radiation at the initial stage (fig. 4) is in accordance to the experimental results [1].

2) For $p$=3, $d$ = 0.14 cm (conditions in [3]), and $U_0$ = 10.4 kV the picture is presented in fig. 5 (for $t$ = 32 ns). A decrease of the radiating channel along all the gap is seen. This confirms our conclusions because in this case the electrons attachment rate is lower and the effect of electrons background is expected to become more important than for $p$=20.
Both the experimental and numerical results testify to principal role of 2D dynamics of microdischarges so any reliable modelling must be at least two-dimensional.

## 4. References


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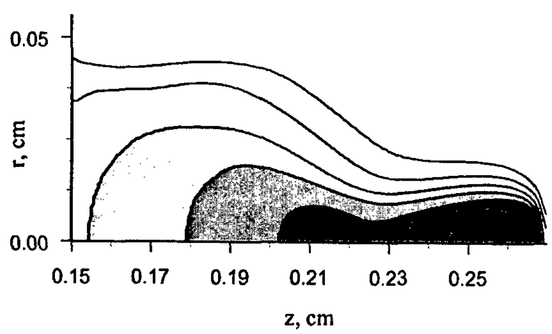


Figure 2: Radiation distribution at λ = 337.1 nm for p= 20 and t=54.5 ns, in photons / cm$^2$ / s (decimal logarithms), low level 16.5, step 1/2.

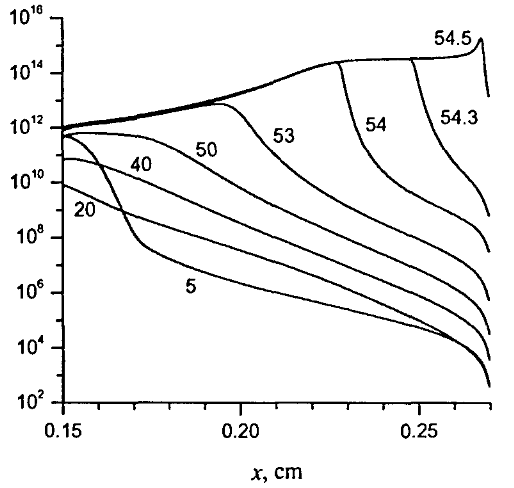


Figure 3: Axial distributions of electrons concentration at the axis for different times, time in ns.

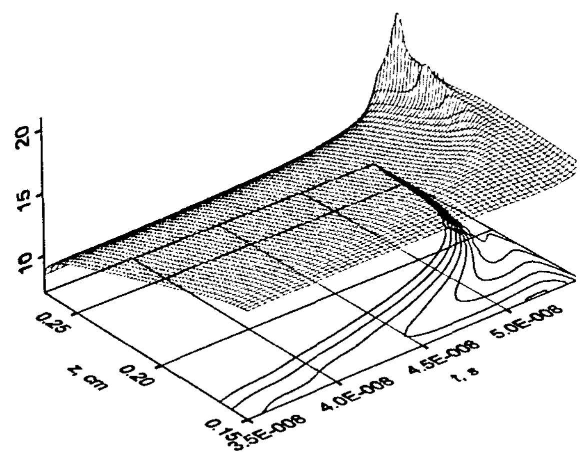


Figure 4: Spatio-temporal dependence for radiation before microdischarge bridging the gap at λ = 337.1 nm, in photons / cm / s (decimal logarithms), low level 15, step 0.25 .

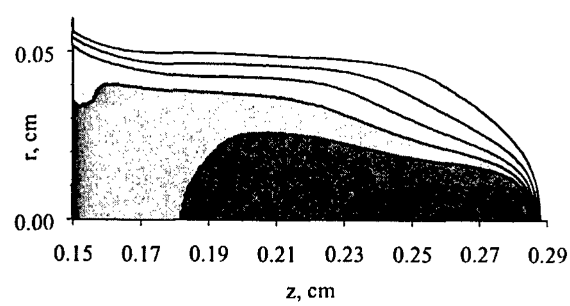


Figure 5: Radiation distribution at λ = 337.1 nm for p= 3 and t= 32 ns, in photons / cm$^2$ / s (decimal logarithms), low level 16.5, step 1/2.